

# Technology Maintenance Readiness Guide for Zero-Emission Buses



Photo by Dennis Schroeder, NREL 46486

## A Guide for Bus Fleet Operators

Transit agencies all over the United States are deploying zero-emission buses (ZEBs), including battery electric buses and fuel cell electric buses. Air quality is the primary driver for adopting ZEBs, especially in states where legislation has been passed to regulate vehicle emissions. The U.S. Department of Energy, through its National Renewable Energy Laboratory (NREL), tracks the progress of these advanced technologies as they are being developed and demonstrated. NREL works with transit agencies and their manufacturing partners to conduct independent third-party evaluations to validate performance under real-world service and report on the status of the technologies toward entering the market. The results are intended to help transit agencies understand the technology status and make informed purchase decisions.

The transition of knowledge from the manufacturers to the transit staff is essential to accelerate the technology. For commercially available bus technologies, an agency's maintenance staff handles all the preventive maintenance activities while the original equipment manufacturer (OEM) provides most unscheduled maintenance under warranty. Once the warranty period is over, the transit staff takes over all maintenance duties. For advanced bus technologies, transit staff must become familiar with new systems and components to troubleshoot and repair any issues.

NREL has developed a technology maintenance readiness level (TMRL) guide for advanced technology vehicle fleets to help fleet operators (such as transit agencies) assess their readiness

level to maintain new ZEBs. This guide mirrors a technology readiness level guide, but it focuses on the ability of the fleet operator to maintain and repair the advanced vehicle technology rather than defining the commercial readiness of the technology itself.

At TMRL 1, a fleet operator begins planning for purchase and integration of ZEBs and may be operating a ZEB on loan from the OEM, which performs all maintenance and repairs of the vehicle at that stage (OEM refers to vehicle manufacturers as well as manufacturers of advanced technology systems/subsystems). The guide outlines the stages through which a fleet operator progresses to become fully prepared to maintain the selected ZEB technology. This includes training maintenance staff, upgrading facilities to accommodate the selected technology (such as adding hydrogen fueling stations or equipment to allow work on high voltage electric systems), developing maintenance manuals, acquiring diagnostic and repair tools, and identifying what parts need to be in on-site inventory. By TMRL 9, the fleet operator is fully capable of diagnosing and repairing any issues with the advanced technology, just as they would with conventional vehicle technologies.

NREL developed the first draft of the TMRL guide based on the experiences collected from various transit agencies demonstrating advanced technology buses. This guide was shared with representatives from all of NREL's current demonstration projects—which include fuel cell electric bus and battery electric bus technologies—for comments and feedback, and NREL improved the guide based on the comments and suggestions provided.

### Industry partners that reviewed the guideline

#### Transit operators

- AC Transit
- Foothill Transit
- Golden Gate Transit
- King County Metro
- Orange County Transportation Authority
- San Mateo County Transportation Authority
- SunLine Transit Agency
- University of California at Irvine

#### Manufacturers and other industry stakeholders

- BAE Systems
- Ballard Power Systems
- California Air Resources Board
- California Energy Commission
- California Fuel Cell Partnership
- CALSTART
- Center for Transportation and the Environment
- ElDorado National - California
- Federal Transit Administration
- Hydrogenics
- Linde
- New Flyer
- Nuvera
- Proterra
- South Coast Air Quality Management District



TECHNOLOGY MAINTENANCE READINESS LEVEL	TMRL DEFINITION	DESCRIPTION
TMRL 1	Initial ZEB demonstration or development of technology of interest	Pre-commercial ZEB (owned by OEM) in limited use by fleet with additional research and development planned by OEM. Fleet initiates modifications to facilities for specific technology.
TMRL 2	Technology selected and implementation planned	Fleet takes ownership/lease of commercially available ZEB. ZEB is operated in limited service and is fully repaired and maintained by OEM (without significant zero-emission component maintenance from fleet staff, fleet contractor, or third-party repair facility). Maintenance staff begins to plan for training.
TMRL 3	Draft training plan developed	Fleet owns/leases ZEBs, which are used in limited or expanded service. Fleet develops a training plan and begins to implement familiarization training for maintenance staff.
TMRL 4	Initial implementation of ZEB technology	OEM is on site doing all maintenance work on advanced technology components; maintenance staff begins doing vehicle-level maintenance work and preventive maintenance inspections. Maintenance manuals and troubleshooting guides are in draft form. OEM is developing special tools needed for advanced technology components. Facility modifications are complete.
TMRL 5	Training of select maintenance staff begins	OEM is on site and begins training select group of maintenance staff on advanced technology components. Maintenance staff is doing all general preventive maintenance inspections and vehicle maintenance but begins assisting OEM with other repairs. Maintenance manuals and troubleshooting guides are in advanced stage of development. OEM and fleet owner are developing spare parts list for technology and identifying what parts need to be in on-site inventory. All maintenance staff has completed familiarization training.
TMRL 6	Training transitioned to select maintenance staff	OEM is on site, but maintenance staff is doing most maintenance with supervision. Select maintenance staff is beginning to train other staff. Maintenance manuals and troubleshooting guides are in final stage of development. Special tools are available and spare parts supplies are readily available for most components.
TMRL 7	Transition of maintenance to staff begins	Select maintenance staff is fully trained and takes on training duties. OEM makes periodic site visits and provides remote assistance. More than 50% of designated maintenance staff is fully trained.
TMRL 8	Transition of maintenance to staff finalized	All maintenance is handled by staff. OEM is off site but available on an as-needed basis (usually remotely). Full manuals are available and all special tools and equipment needed have been acquired and incorporated into the facility. A large percentage of designated maintenance staff is fully trained. Training curriculum is complete.
TMRL 9	Maintenance staff fully maintaining ZEBs	All designated maintenance staff are trained on ZEB technology. Training is incorporated into standard training program. Spare parts are readily available for all components. OEMs have regional support centers or third-party repair facilities are available. Maintenance and repair training is available from external organizations (e.g., technical schools, community colleges); incoming maintenance staff is fully trained.